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FEASIBILITY STUDY OF SOLID SURFACE SUBREFLECTOR
PRODUCTION TECHNIQUES

FINAL REPORT



JPL-FACC CONTRACT NUMBER 956137

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ABSTRACT

A technical and economic feasibility study on single surface, non-welded subreflector production techniques was conducted. The principal production techniques under investigation was spin forming a subreflector reflective surface, backing the surface with fiberglass to provide stiffening and machining the spun surface to a tolerance of .008 inches Root Mean Square (RMS).

The costs for this production technique were verified for subreflector sizes up to 150 inches. Alternate techniques were examined for sizes up to 452 inches; and cost estimates were prepared for two production techniques.

This was a theoretical study and no actual experiments of the production processes were conducted.

SUMMARY

This is the final report presenting the results of a feasibility study on single surface, non-welded subreflector production techniques. The principal effort was to study technical feasibility and cost aspects of the production technique of spin forming a subreflector reflective surface to a desired surface of revolution, back the surface with fiberglass to stabilize it sufficiently so that it may be machined to the target surface tolerance of .008 inches Root Mean Square (RMS) with a goal of .003 inches RMS.

To verify this production technique, analyses was performed to define the production procedure. A price estimate for a 150 inch diameter subreflector for a 34 meter cassegrain antenna.

During this feasibility study, numerous production processes were evaluated theoretically as production approaches for single surface, non-welded subreflectors. The first successful was the principal process of spin forming the reflective surface, backing with fiberglass and machining to a final contour. The second successful process was spin forming or bump forming a thicker reflective surface, with an integral (welded in) structure as a backing and machining the mounting pads and reflector to a final configuration. No experimental hardware was fabricated to verify either process.

The principal process was evaluated in sizes up to 452 inches which was narrowed to two test sizes used for complete evaluation. The test sizes used were 84 and 150 inch diameters. Some information was obtained on sizes up to 312 inches but a complete evaluation was not possible due to inability to locate sources for the various operations and funding limits. The 84 inch diameter size would utilize a spun outer surface of 1/4 inch thick aluminum backed by fiberglass stiffening, the aluminum being machined to a final contour of approximately .003 inches RMS. The product in this size should cost approximately \$125,000 for a single unit, including a tooling, cost of \$35,000 and approximately \$40,000 per unit in production quantities of 5 to 10 units. The 150 inch size would utilize a solid, spun outer surface of approximately 3/8 inch thick aluminum backed with fiberglass, with the aluminum machined to a final contour of approximately .006 inches RMS. The unit price for a single unit in this size, as estimated including tooling at \$85,000, should be approximately \$250,000 and approximately \$80,000 per unit in production quantities of 5 to 10 units. Production quantity costs (5-10 units) do not contain tooling amortization as the value would vary depending on the exact quantity.

The alternate process was studied and verified for subreflector sizes up to 180 inches in diameter. For subreflectors with a diameter in excess of 180 inches up to 452 inches, other factors such as stress relieve machining sources and shipping become major limiting factors.

This alternate process employs a spin formed or bump formed aluminum outer solid reflective surface backed by an integral aluminum welded structure for stiffening and structural integrity. The fabricated structure is then machined to the final contour and surface tolerance will vary from .003 inches RMS for sizes in the 84 inch range to .008 inch RMS for sizes in the 180 inch diameter range.

The estimated cost for an 84 inch diameter subreflector fabricated by this alternate process for a single unit, including tooling, should be approximately \$115,000. Production cost for a single unit in quantities of 5 to 10 units would be approximately \$35,000, not considering the cost of tooling. (Tooling cost estimated to be \$36,000 through G&A and profit.)

The estimated cost for an 150 inch diameter subreflector using this process should be approximately \$210,000 for a single unit, including tooling. Production cost for one unit based on quantities of 5 to 10 units would be approximately \$60,000, not considering the cost of tooling. (Tooling cost estimated to be \$86,000 through G&A and profit.)

If the bump formed process is used, the total cost would be less for single units as there is practically no tooling cost involved. The 150 inch size would be approximately \$60,000 less due to tooling costs. The material price would be slightly higher because a thicker blank is required to start due to increased tolerance on forming the curve by the bump form process.

Detailed process procedures and cost data was not developed for sizes in the 200-452 inch range. The decision was made due to funding limits to place major emphasis on the sizes where complete data could be obtained. Some information was obtained on the alternate process for a 312 inch size but the cost information for sizes above 180 inches is incomplete as indicated on the cost curve figures shown later in this report.

Table I depicts a summary of the results of this solid surface subreflector study.

Table I. Summary of Results

Process	Diameter (inches)	Aluminum Thickness (inches)	RMS Inches After Machining	Cost of Single Unit with Tooling \$(1000)	Cost of Single Units of 5-10 Units \$(1000)	Tooling Cost \$(1000)
1						
Spin forming with fiberglass backing and machined to final curve	84	1/4	0.003	125	40	35
	150	3/8	0.006	250	80	85
2						
Spin forming with integral welded-in backup structure and machined to final curve	84	3/4	0.003	115	35	35
	150	3/4	0.006	210	60	85
	256 to 312	3/4 - 1 welded prior to spinning	0.001 0.010	Incomplete	Incomplete	Incomplete
3						
Bump forming with integral welded-in backup structure and machined to final curve	84	1 1/4	0.003	95	35	5
	150	1 1/4	0.006	150	60	5
	256 to 312	1 1/2" bump formed circular plate for 256" size 1 1/2" bump formed pie sections weld assembled for sizes to 312	0.001 0.010	Incomplete	Incomplete	Incomplete

1.0 INTRODUCTION

This final report is prepared in accordance with Fixed-Price Research and Development Contract Number 956137 for a Feasibility Study on Non-Welded Subreflector Production Techniques. The report includes a summary of all the work performed, a technical discussion, conclusions, recommendations, and a new technology statement. The report has been prepared to conform with JPL Specifications 1030-24 Rev B, 1030-26 Rev C, and 1030-29 Rev. A.

2.0 OBJECTIVE

The objective of this contract was to verify the production technique of spin forming a subreflector reflective surface to a desired surface of revolution, then back the spun surface with fiberglass stiffening to stabilize it sufficiently so that it could be machined to the desired surface tolerance of .008 inches Root Mean Square (RMS) target with a goal of .003 inches RMS.

If the production technique, when studied, proved successful then perform the following analysis:

- o Define the production procedure used.
- o Estimate the price of a 150 inch diameter 34 meter subreflector and of subsequent size increases up to 452 inch diameter or the production limit defined by the study.

If the production technique described above appeared to be unachievable, recommend an alternate technique and perform the same analysis.

3.0 TECHNICAL DISCUSSION

During the performance of this contract effort, Ford Aerospace & Communications Corporation (FACC) has surveyed the spin forming industry regarding spinning techniques, required layup techniques for stiffening the spun surface, and evaluated machining techniques for providing the final surface and accuracies obtainable by machining a single surface non-welded subreflector. This production technique was considered the principal approach. Also investigated, as an alternate, was a technique for producing subreflectors without fiberglass backup. Size and weight limitations were evaluated and curves were plotted on RMS accuracy versus diameter.

Cost data has been generated for both of the above fabrication techniques on a basis of cost versus diameter. A weight versus diameter curve was also generated.

The following paragraphs describe the results of the contract study.

3.1 Principal Production Process

The principal production process evaluated was the spin formed method with fiberglass backing, machined to the final contour.

3.1.1 Spin Forming

The spin forming industry was surveyed and data regarding fabrication techniques, size limitations, tooling, material and cost data were obtained. The two main sources investigated were Spincraft in North Billerica, Massachusetts and Metal Spinners Inc. of Angola, Indiana.

One of the oldest of metalforming processes, spinning has been slow to incorporate modern equipment and control but is now coming on strong. With programmed templates, numerical control, and tooling innovations, high volume automatic production of spun parts at a competitive price is a reality. These developments have also led to new directions in part design. In addition to competing directly with other metalforming processes, spun shapes are often combined with cast, drawn, forged, or machined parts in ways that increase precision and reduce costs. Figure 1 shows typical steps employed in the spinning process that would be used in a subreflector.

The spinning process has traditionally offered a number of advantages for chipless production of limited quantities of circular, hollow shapes. These advantages are:

- o Tooling cost is low if a modest production quantity is required
- o Set-up time is rapid
- o Design changes are easily made
- o Work piece material or thickness can be changed easily
- o Plastic flow of the metal during spinning refines the grain structure and increases tensile properties

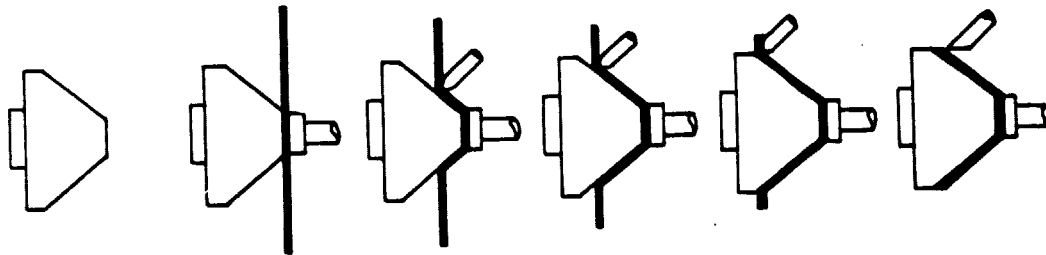
But there are disadvantages in conventional spinning:

- o The process is slower than deep drawing
- o Uniformity of production depends heavily on operator skill
- o Available forming force in manual and mechanical-assist spinning is limited

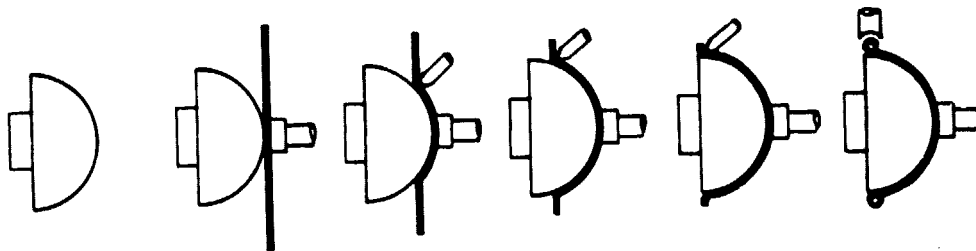
Power spinning, made possible by adapting hydraulic systems to spinning lathes, has provided the muscle that eliminates the available-force limitation. Today, parts as large as 25 feet in diameter, spun from heavy gage steel and other metals, are not unusual. Power spinning, applied to the production of smaller parts, also reduces production time, making spinning more competitive with deep drawing.

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STEPS IN SPINNING A CONE



STEPS IN SPINNING A HEMISPHERE



STEPS IN SPINNING A CYLINDER

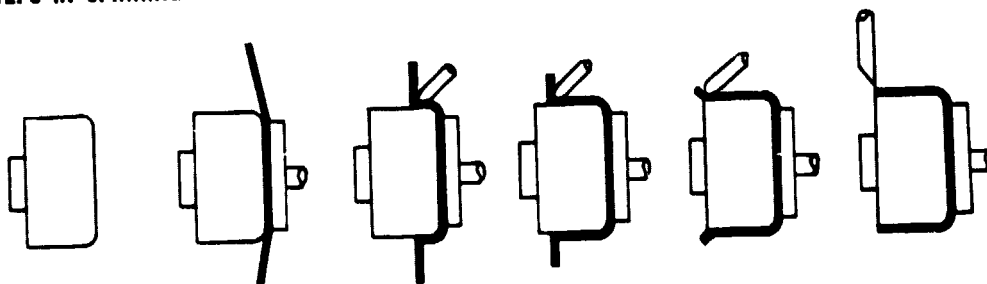


Figure 1. Spinning Process (Steps in spinning a hemisphere most closely depicts process for subreflector)

3.1.1 (Continued)

Recent advances in spinning technology involve programmed templates and numerical control. In a typical production sequence, a stylus (which controls the hydraulically-operated forming roller) follows the contour of one of several stacked templates. The stylus then steps down to the next template and repeats the process until the part is completed. A variation of this method uses a swivel template instead of a stacked arrangement. With either system, the sequence is programmed and is easily varied to accommodate different shapes, sizes and materials. These automated spinning lathes can copy the motions a craftsman would use in producing the part manually.

Several spinning sources were contacted by telephone and the two mentioned (Spincraft and Metal Spinners Inc.) were visited. The following information directly applicable to the contract requirements regarding the fabrication of a spinning for the use of an outer reflective surface of a subreflector was obtained.

- o The most common aluminum material successfully used and recommended by all spinning sources: 1100-0, 3003-0, 5052-0 and 6061-0. These materials have proven to be the most desirable to produce large spun shapes with the best tolerances.
- o Spin formed solid reflective surfaces up to 180 inches in diameter can readily be produced in material thickness of 1/4 to 3/4 inches using the aluminum material described above. The nominal tolerance that can be obtained in the largest sizes is approximately $\pm 5/32$ inch. These tolerances can be improved if more work is done on the spinning (more passes of the spinning tool). This additional effort increases the cost of the final part. In sizes up to 96 inches, the tolerance reduces to approximately $\pm 3/32$ inch and further reduces for smaller sizes.
- o Blanks up to 312 inches in diameter can be spun with an accuracy of $\pm 5/16$ to $\pm 1/2$ inch obtainable, these are the tolerances specified by Spincraft located in Massachusetts. For special applications, closer tolerances are possible for additional cost.
- o The normal spinning tool used is made of wood; for most work the wooden tool is used because of its ability to be re-dressed, as necessary, to obtain the proper curve without removing the tool from the spinning table.
- o Aluminum plates up to $1\frac{1}{2}$ inches thick can be spin formed if a steel spinning die is used and a hydraulic pressure head is available for applying the spinning force.
- o The steel spinning die is also recommended when tighter tolerances are required (tolerances closer than the values mentioned above).

3.1.2 Aluminum Material Size and Weight Limitations

The maximum width sheets of aluminum now being rolled at the Reynolds and Alcoa plants are as follows:

- o Reynolds Plant - West Virginia

The Reynolds aluminum rolling mill produces aluminum sheet or plate in widths up to 132 inches and thickness up to 1/2 inch. The material can be cut to any desired length that can be shipped.

- o Alcoa Plant - Davenport, Iowa

The Alcoa aluminum rolling mill produces sheet or plate 136 inches wide in thicknesses up to 3/8 inch, 160 inches wide in thicknesses 1/2 inch to 7/8 inch and 180 inches wide in thickness of 1 inch.

All of these sheets of material must be procured by purchasing a mill run. The mill run is normally around 8000 pounds and the material cost is approximately \$1.50 per pound.

The maximum width of a sheet determines the maximum blank diameter that can be used for spin forming. Sheets can be welded together, using a machine weld technique and the proper welding rod, to produce larger sheets. This is commonly done when the production run is small to avoid the high cost of procuring a mill run of material. When welding is complete, the material is annealed to provide the best possible condition for spinning welded material. The surest approach to eliminate chances of cracking is to use the as-rolled material in "O" grade without welding.

3.1.3 Stress Relieving Spin Formed Parts

For the spun aluminum outer shell where thinner materials (up to 1/4 inch thick) are used, normally one stress relieve operation is adequate and this is performed just prior to making the final spin form pass. In most cases the process used is to anneal the material from its spun condition back to "O" grade. Following the final spinning, the finished part will age harden to a T4 condition.

Where thicker outer reflective surfaces are utilized and hydraulic spinning equipment is used, additional stress relieve operations must be performed. In these operations, rather than actually annealing the part as described above, stress relieving is performed by heating to 400°F for 20 to 25 minutes. The final stress relieving operation is performed just prior to making the final spinning pass on the part. This pass is usually done to improve surface accuracy.

3.1.4 Fiberglass Layup

The fiberglass layup backing procedure was investigated as a means of stiffening the spun aluminum skin and improving the machining characteristics of the aluminum surface. It is a complete layup using the spinning, several layers of fiberglass and polyester resin, and aluminum honeycomb or a plastic closed cell foam material. This forms a composite structure which is sufficiently stiff to permit machining and to provide structural integrity for the front surface.

The procedure investigated requires the use of a female mold prepared to the shape of the final subreflector. The mold is required to hold the spinning in its true spun shape while the fiberglass layup is being performed. To insure that the spinning is held to the mold, the edges are sealed and a vacuum is pulled on the tool; the vacuum is held during the layup and layup cure cycle. This allows the proper shape to be stiffened into the aluminum outer shell.

The fiberglass backing consists of radial ribs and some thickness of material applied over the entire surface of the spinning that has layers of fiberglass and polyester resin applied both over and under these stiffening members (see Figure 2). The thickness varies with the depth of curve and the thickness used for the reflector surface. In the case of a flat curve, like the JPL 96 inch subreflector, 2 inches or more would be required and then special retention of the pre-stiffened spinning is necessary during machining.

3.1.5 Final Machining

The final reflective surface of the solid surface subreflector would be machined to the final curvature on a vertical lathe. Machines that would readily handle sizes in the 12 to 15 foot diameter range have been located. For sizes larger than 15 feet, a special source must be identified. Oliver Johnson, San Jose, California can handle up to 15 feet.

Through information obtained from these sources, the achievable surface accuracy would be .003 RMS for diameters up to 96 inches, .005 to .006 RMS for diameters up to 180 inches and .010 for diameters up to 312 inches. This depends somewhat on the machine, its age, and how it has been maintained along with the depth of curve for the part to be machined. No information was obtained for sizes beyond 312 inches. Twenty-one of this type subreflector, using the principal production process, were manufactured by WDL in the 84 inch size and all had surface accuracies as machined in the .003 inch RMS range.

In a case like the JPL 96 inch subreflector where the curve is shallow, it appears that in addition to the 2 inches or more of stiffening material, it would be necessary to provide a holding fixture that is representative of the backup structure for the finished subreflector. By providing this kind of control, the finished part should return to its machined shape when mounted in the field.

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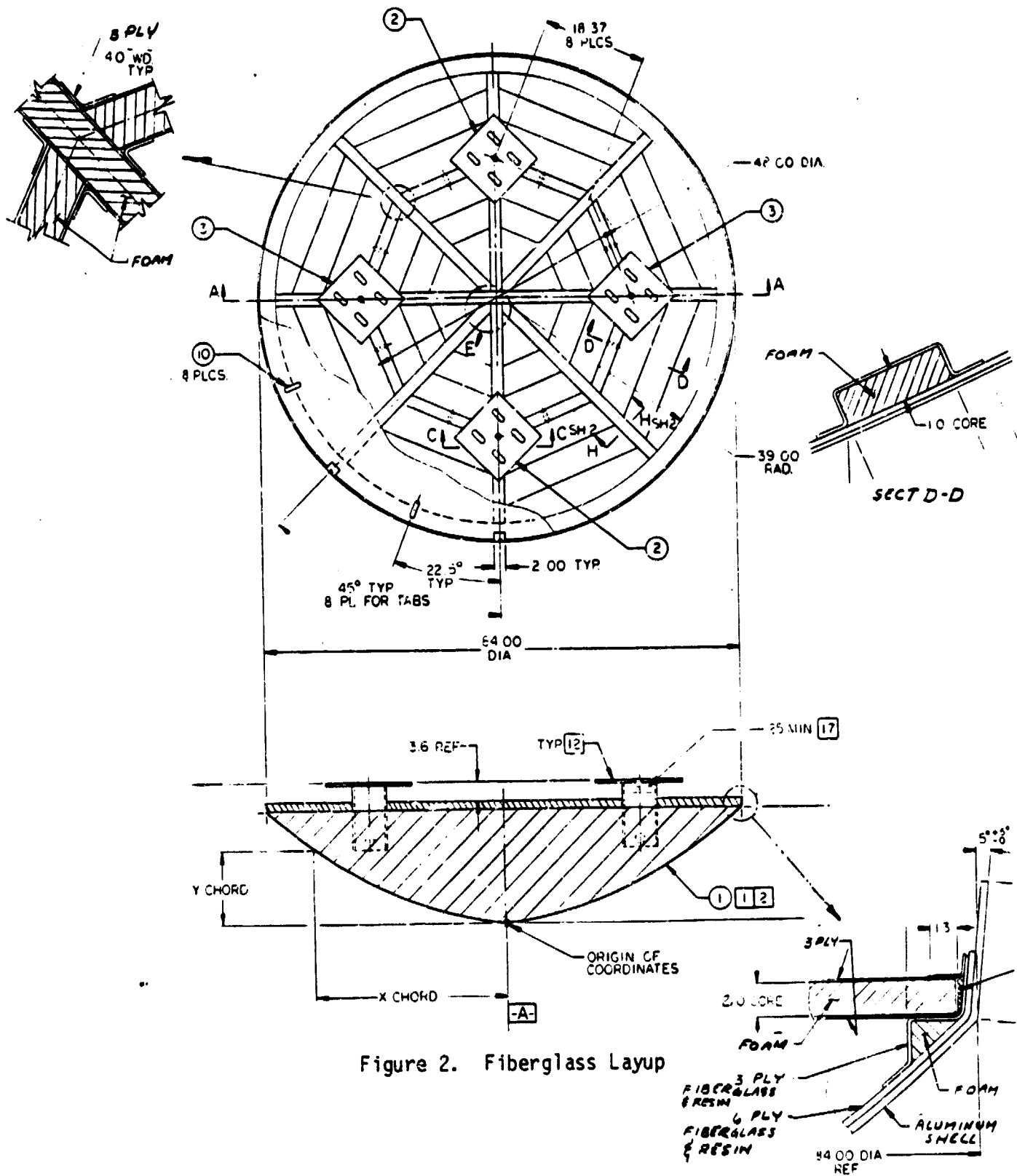


Figure 2. Fiberglass Layup

3.1.5 (Continued)

The process for machining that appears most practical is to generate a tracer template incorporating the final subreflector curve and, through use of a trace adaptor and stylus, on a vertical lathe machine the stiffened spun aluminum surface to the final contour.

3.2 Alternate Production Process

When the alternate production process was first investigated, it was being considered for sizes in the 150 inch diameter ranges and larger. During cost evaluation it was determined that the alternate process would be competitive even for the smaller sizes. The alternate process studied utilizes a thicker spun aluminum reflective surface (1/2 to 3/4 inch thick) or a bump formed outer surface up to 1-1/2 inches thick. The surface stiffening is then accomplished by welding in aluminum stiffening and final machining is done in a manner similar to the principal process described above.

The following paragraphs describe the production technique for the alternate process.

3.2.1 Spin Formed or Bump Formed Outer Reflective Surface

If a spinning is used for the outer reflective surface for this concept, it will be made using aluminum material that is 1/2 inch to 3/4 inch thick. The spinning and stress relieving will be performed in the same manner as described in paragraphs 3.1.1 and 3.1.3. Spinings for this concept can be made up to 180 inches without using welded material, a steel spinning tool should be used; spinings up to a 312 inch blank size can be made using material that is pre-welded.

Another process for providing the outer reflective surface is bump forming (see Figure 3). The process starts with a disc of aluminum placed in the center of a machine that has a localized female die that has been machined to the desired radius. The ram of the machine contains a male die that has been machined to the same contour as the female die. Pressure is applied to the material that has been placed between the two dies, forming a dimple in the material. The material is rotated and additional dimples or bumps are made until the disc conforms generally to the curve of the die set. The dies are cut to a spherical radius and the machine will generate a curve to any spherical radius.

If a parabola is required the source will bump form to the nearest best fit spherical radius or they will try forming to the parabola. This source has not bump formed to a parabola to date but feel they can and they are willing to try.

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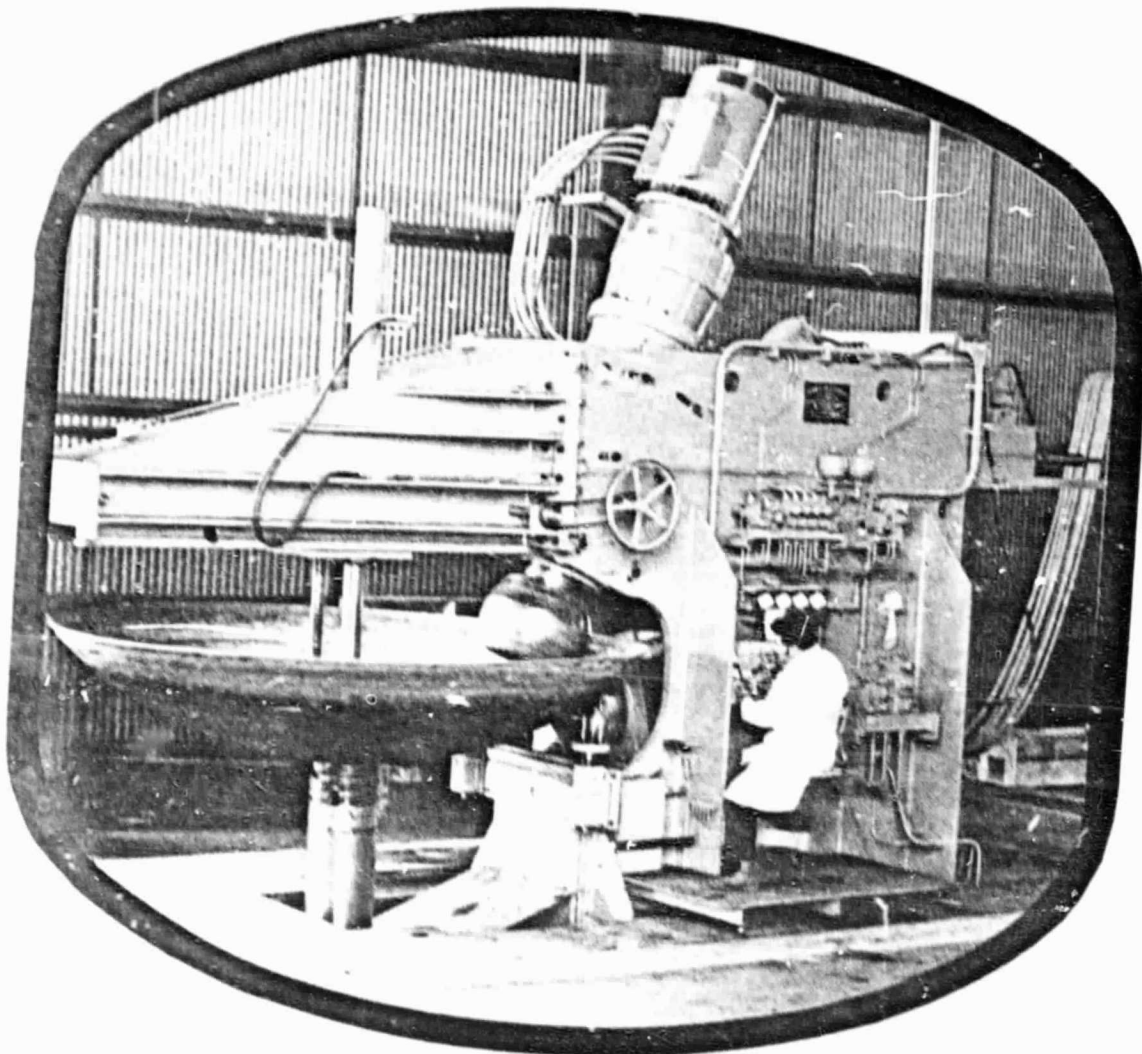


Figure 3. Bump Forming

3.2.1 (Continued)

The tolerance can be held (in the 1/2 inch range) is the reason that the starting material thickness must be greater; the range of thickness for the process is 3/4 to 1-1/2 inches. There is obviously more final machining required for this process but the tooling cost to provide the reflective surface is considerably less. This special machinery can handle discs up to 22 feet in diameter, if aluminum material in that size was available. The shop is Orange Country Machine Works located in Orange, California. The 22 foot disc would cover sites to 256 inches and bump forming pie-shaped 503 MHz followed by welded construction would handle sizes to 312 inches. Figure 4 is a sketch showing this type construction, Figure 5 shows a typical weldment. The part is shown in two sections that would be bolted and dowelled together during machining so that separation would be possible for shipping.

3.2.2 Reflective Surface Stiffening

The reflective surface stiffening for the alternate process is provided by preparing an aluminum weldment that will fit into the pre-formed reflective surface. The aluminum weldment, when completed, is welded into the outer shell using a skip welding procedure and alternating the location for the welds so that stresses will not be concentrated and surface distortion will be kept to a minimum.

3.2.3 Stress Relieving Fabricated Structure

The stress relieving operations for this process should be the same as those described in paragraph 3.1.3 for the spinning or bump formed part. When welding has been completed, a stress relieving operation should be performed by heating the weldment to 400°F in a furnace and holding at this heat for 20 to 25 minutes. The part is then air cooled.

3.2.4 Final Machining

When the welding and stress relieving is complete, the support legs and reflective surface will be final machined. The support legs will be machined first, after having set the subreflector on the machine to best distribute the machining stock for the reflective surface. When the support legs have been machined flat, the part will be turned over such that it is resting on the support legs. After centering the part properly with the machine table, the reflective surface will be machined using a series of cuts until the entire surface is cleaned up. The part will be rough machined to within approximately 1/16 inch of clean up and again stress relieved by heating to 400°F for 10 to 15 minutes and air cooling. Machine to within .020 inch of clean up and once again stress relieve by heating to 400°F for 10 to 15 minutes and air cooling. The subreflector reflective surface will then be machined to final curve achieving the same accuracies described in paragraph 3.1.5. Approximately one half of the aluminum shell will have been machined away during the machining operation.

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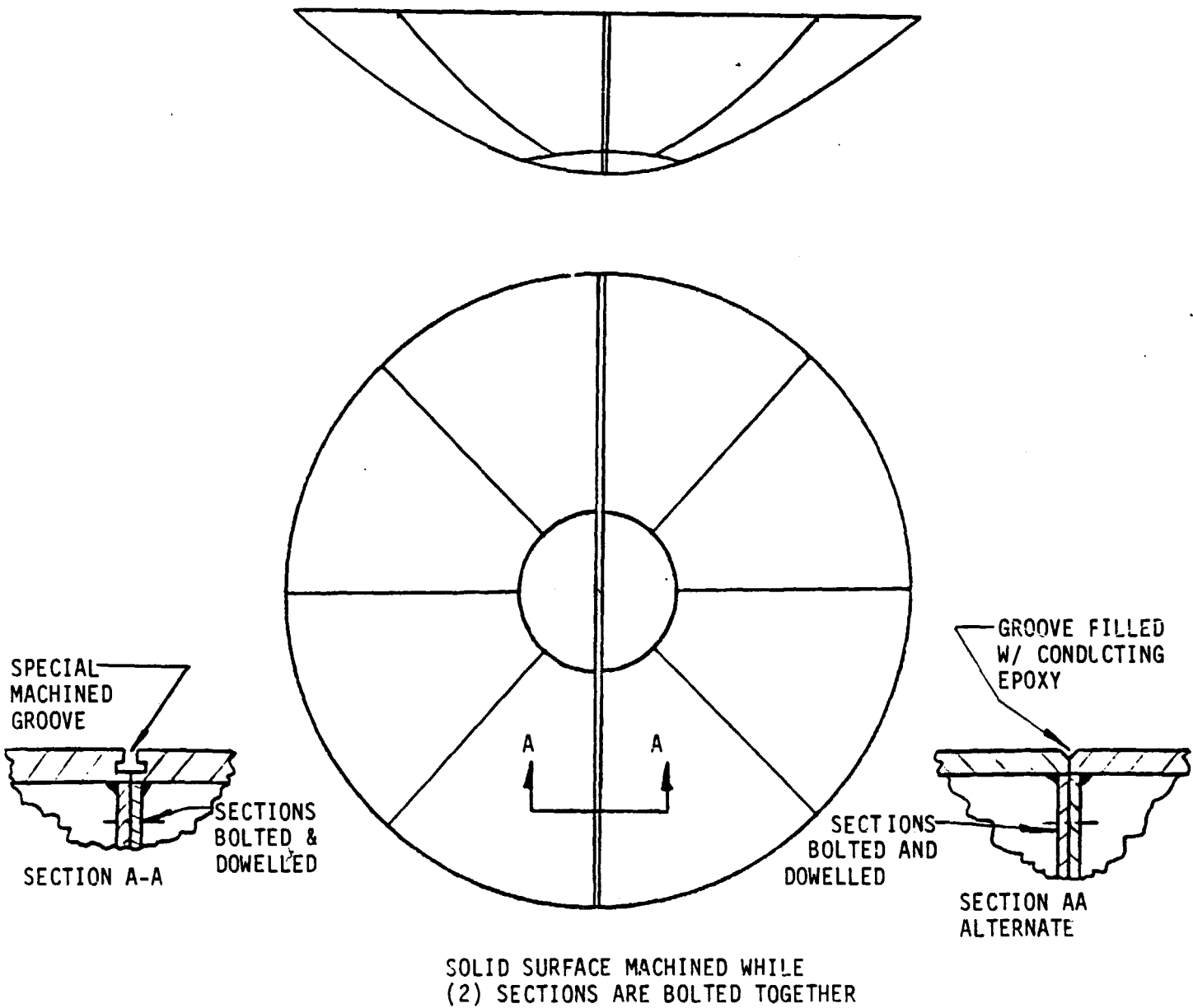


Figure 4. Two Piece Pie Section Bump Formed, Welded Construction

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Figure 5. Bump Formed, Welded Construction Similar to Proposed
Process for Large Dia. Subreflectors

3.2.4 (Continued)

Special attention should be given to holding the part on the machine table so that residual stresses are not induced due to clamping. Sharp, properly ground cutting tools should be used to prevent cold working the surface and inducing residual stresses that will cause distortion.

Figure 6 is a diameter versus accuracy curve that is generally applicable to the final machining of the principal and the alternate types of subreflector. The curve was generated from data obtained during WDL fabrication of twenty-one 84 inch subreflectors and data obtained from suppliers on 150 inch size. Oliver Johnson in San Jose has machining capability for sizes up to 180 inches in diameter. Westinghouse in Sunnyvale has two large vertical lathes; one will handle diameters up to 256 inches and the other will handle up to 480 inches.

3.2.5 Weight Versus Diameter

A weight versus diameter study was conducted; the result applies mainly to the alternate process. Figure 7 shows a curve that is generally applicable to the various subreflector sizes fabricated using the alternate process; most would be lighter if the principal process was used.

4.0 FABRICATION COST DATA

Cost data has been prepared for subreflectors fabricated by both the principal and alternate processes. The alternate process included only spin forming for the reflective surface as not enough information was available to include bump forming in the cost. The cost elements considered while preparing the cost data are as follows:

<u>First Article</u> <u>(single unit)</u>	<u>Production</u> <u>(5 to 10 units)</u>
Tooling	Material and spinning
Material and spinning	Backup frame
Backup frame	Machining
Machining	Engineering support
Design	Contingency
Engineering support	G & A
Contingency	Profit
G & A	
Profit	

Figure 8 shows cost curves for both prototype and production units for the principal process. It shows the cost for a prototype in the 84 inch size to be approximately \$125,000 with the cost of production unit being approximately \$40,000 considering 5 to 10 units. The 150 inch size would cost approximately \$250,000 for a prototype and \$80,000 for a production unit considering 5 to 10 units.

Figure 9 shows cost curves for both prototype and production units for the alternate process.

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Accuracy Versus Diameter
Curve Based on 3 Data Points

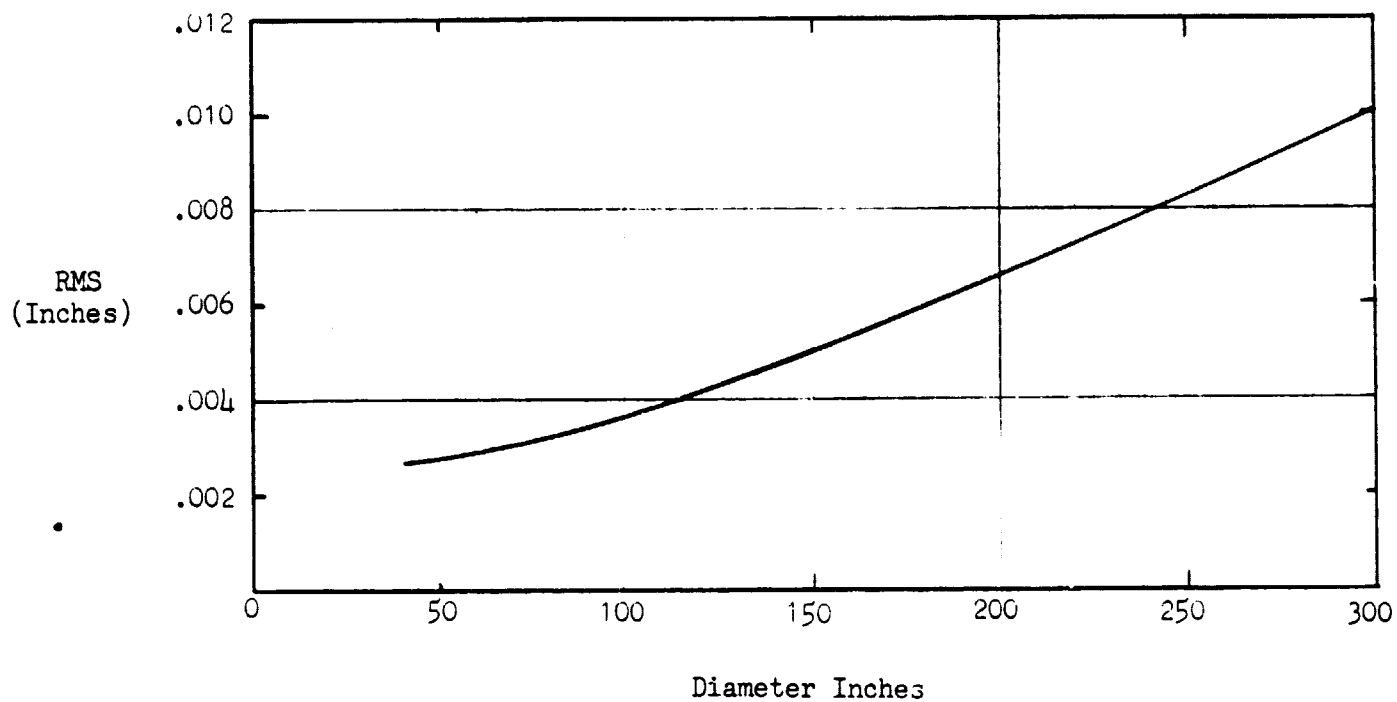


Figure 6. Accuracy Versus Diameter

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Weights for sizes above 150 inches were not estimated

Curve based on 2 data points

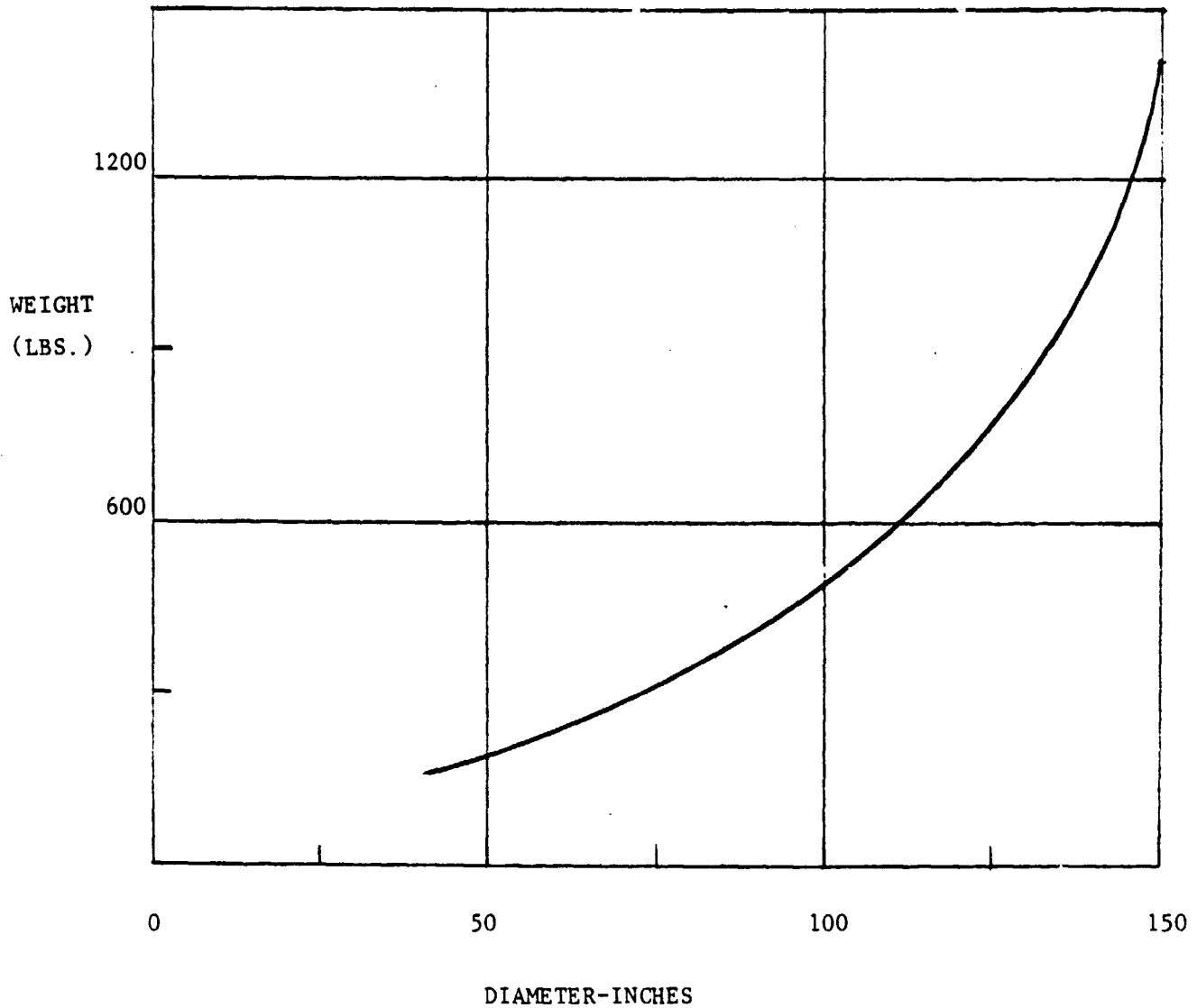


Figure 7. Weight Versus Diameter

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Two firm data points for each curve based on 84" and 150" sizes

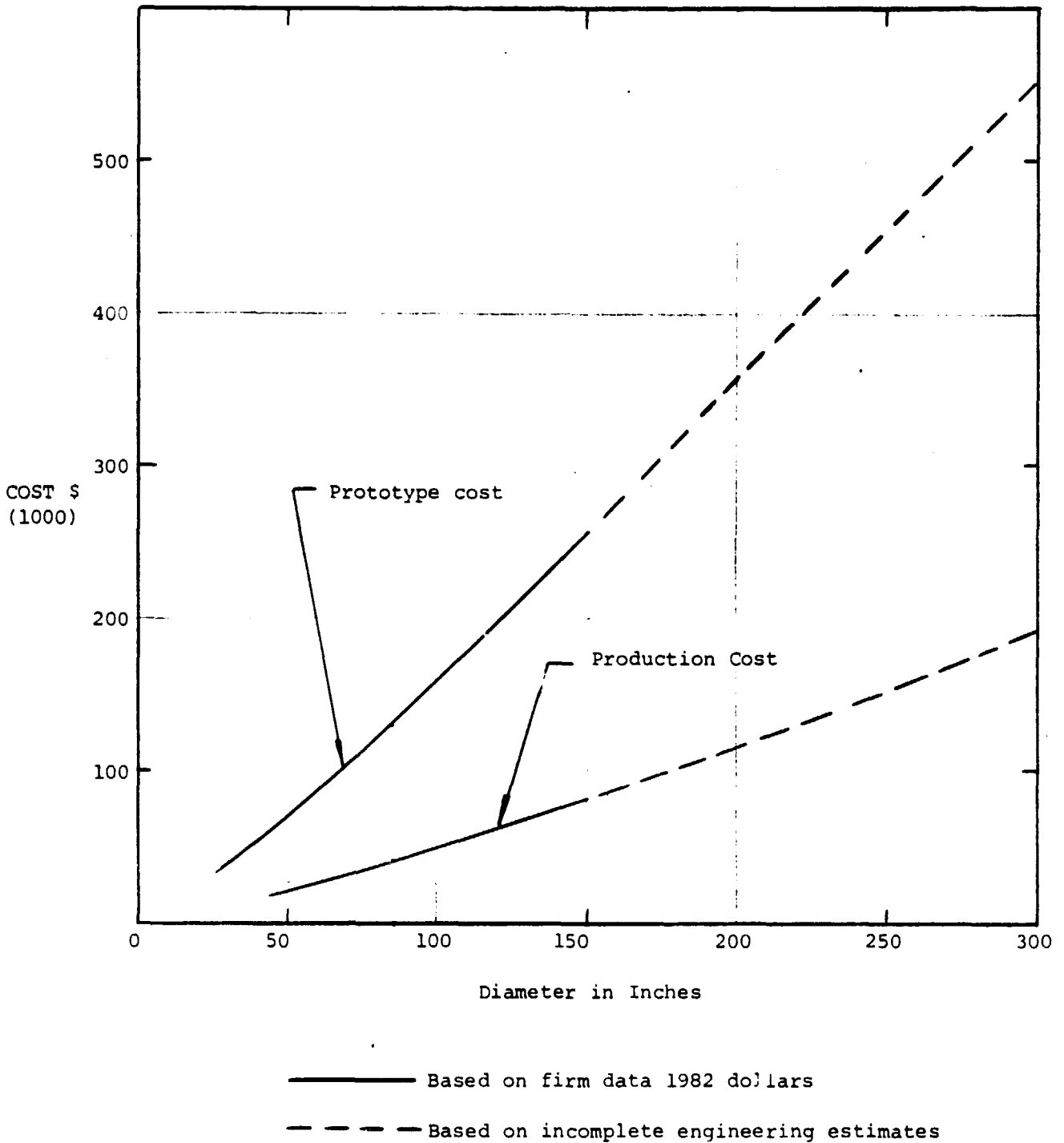


Figure 8. Cost Curves for Spin-Formed Subreflector
with Fiberglass Backing

Two Firm Data Points for Each Curve Based on 84" & 150" Sizes

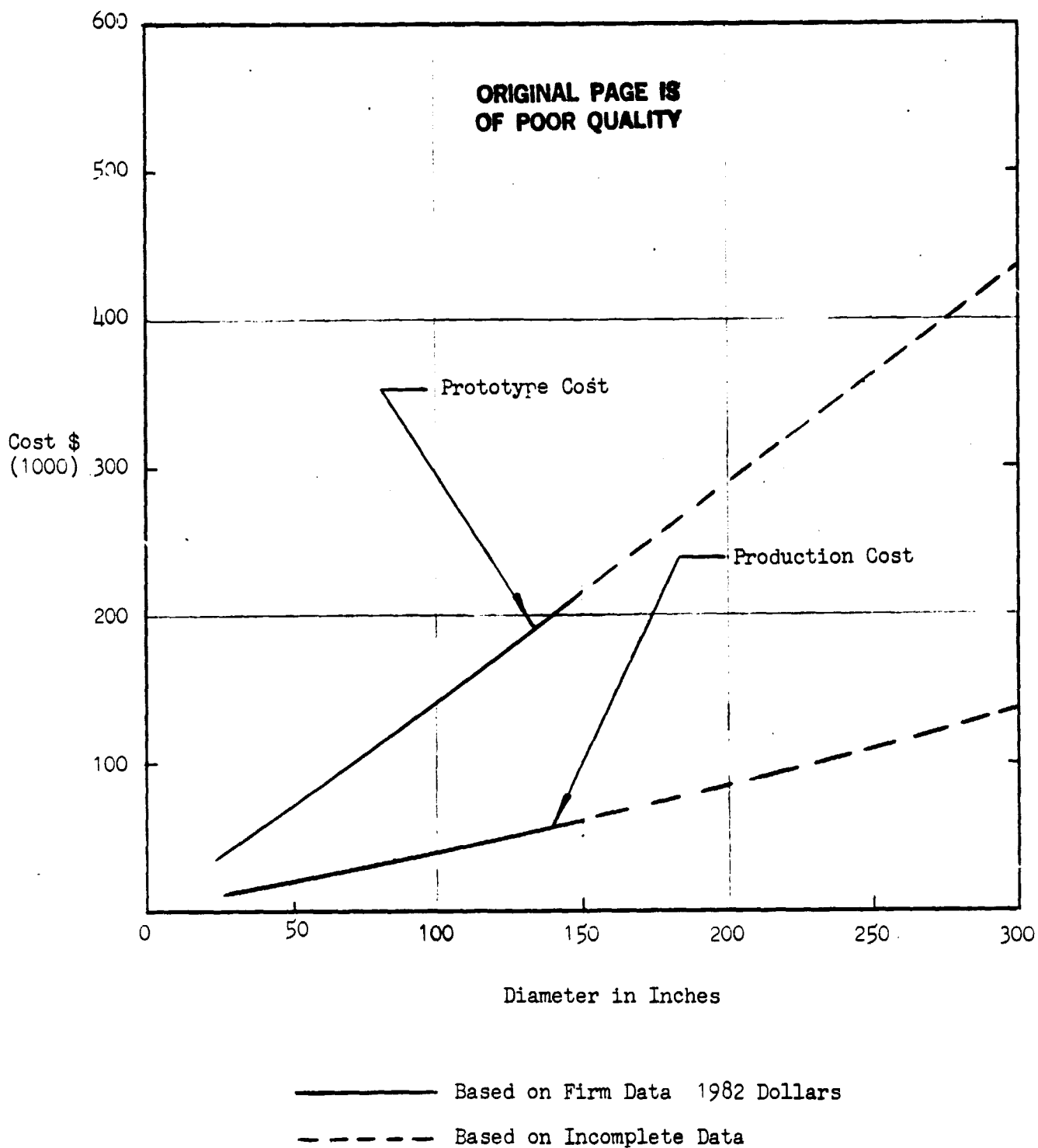


Figure 9. Cost Curves for Spin-Formed Subreflector without Fiberglass Backing

4.0 (Continued)

It shows a prototype in the 84 inch size would cost approximately \$115,000 with a production unit costing approximately \$35,000 considering 5 to 10 units. The 150 inch size would be approximately \$210,000 for a prototype and approximately \$60,000 for a production unit considering 5 to 10 units.

Figure 10 shows cost curves using the bump formed process to produce the outer shell. As can be seen the cost is approximately \$30,000 less for the 84 inch size and approximately \$75,000 less for the 150 inch size. The cost reduction is due to the reduced cost for tooling. There is only a very small cost for tooling using the bump form process.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been developed.

5.1 Conclusions

- o The principal production process is recommended for sizes up to approximately 100 inches.
- o The alternate production process is recommended for sizes 100 to 312 inches.
- o Both processes are constrained for sizes above 180 inches for the following reasons:
 - Non-welded aluminum material is not available in widths over 180 inches, however welded aluminum can be spin formed up to 312 inches with some loss of accuracy and increased cost. Bump formed welded material has not been tried.
 - Vertical lathes are available to turn sizes above 180 inches but sources are very limited. Westinghouse Marine in Sunnyvale, California can turn sizes up to 40 foot diameter.
 - Heat treat and stress relieve sources are available for sizes larger than 180 inches but again are limited. A source in San Francisco has committed to handling up to 312 inches.
 - Shipping a single piece over 180 inches becomes more difficult. It may be necessary to make 2 pieces of the larger sizes to permit reasonable shipping, or consider special handling such as helicopter lift. A special groove would be designed to prevent arcing at the joint (see Figure 4). To develop the joint will require additional investigation.
- o Cost of units fabricated by the alternate process appear to be less for all sizes up to 180 inches. Detailed costs on larger sizes could not be obtained under the funding limits of this study effort.

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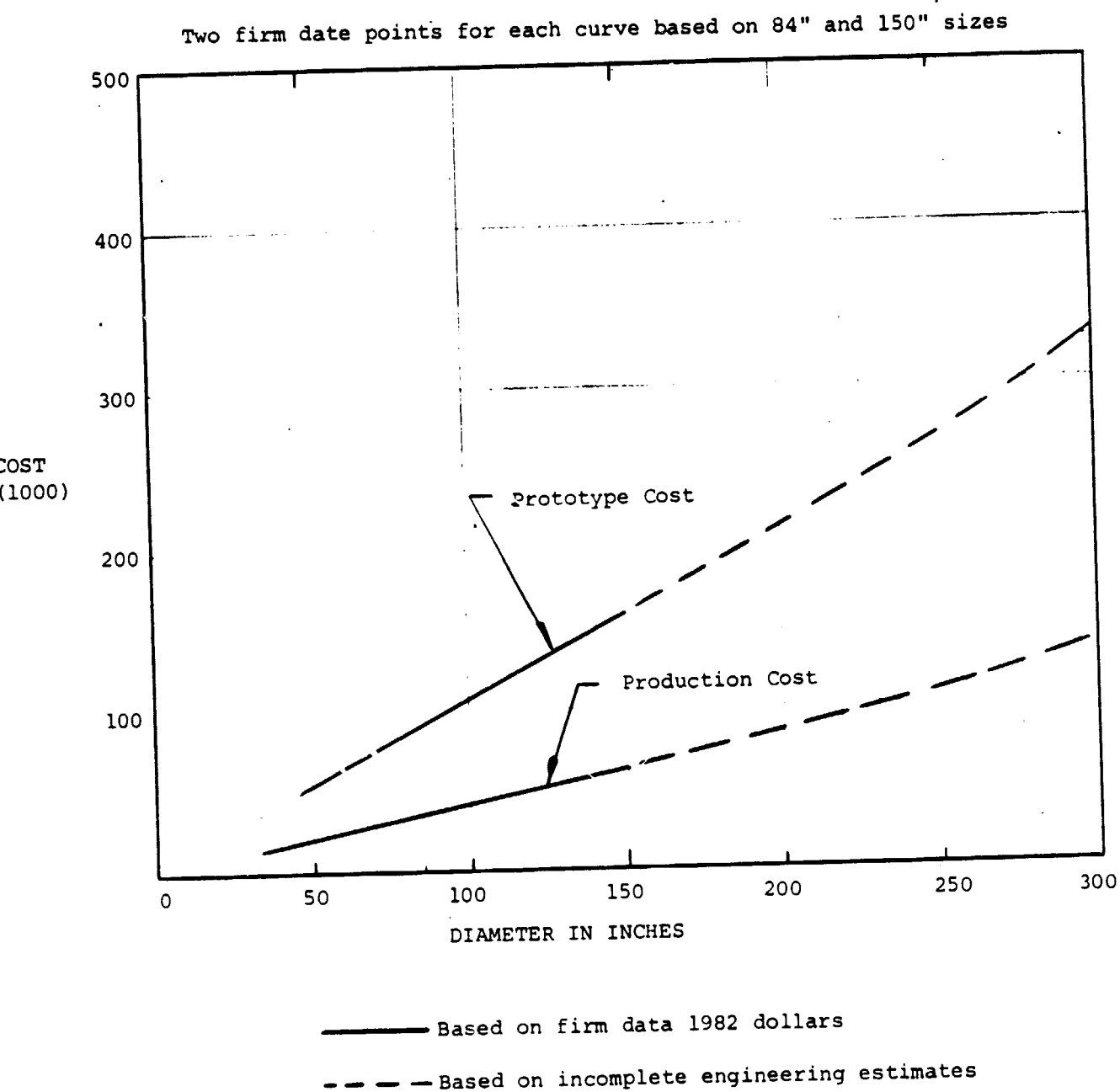


Figure 10. Cost Curves for Bump-Formed Subreflector without Fiberglass Backing

5.1 (Continued)

- o For sizes larger than 180 inches, limited investigation was made into subreflectors containing a spin formed outer surface and also bump formed segments welded together as a reflective surface. As an alternate process this would not conform to the intent of the contract (i.e., single surface, non-welded, subreflector production techniques). A subreflector produced in this manner would have to be shipped in segments and reassembled at site.

5.2 Recommendations

- o Additional study efforts should be conducted on the alternate process for larger sizes (200-312 inches) to verify results obtained to date and to complete cost data on the process.
- o Fabricate an experimental model of the best candidate following completion of the additional study effort. This would prove the production process for the best concept. The cost of this effort for sizes in the 84-150 inch sizes can be extracted from the appropriate curve. For larger sizes additional costing would be required before an exact value could be given.

6.0 NEW TECHNOLOGY

A new technology can be claimed as a result of this study for the alternate process. A subreflector fabricated by the alternate process has never been attempted at WDL. WDL has no knowledge that this technique has been utilized by others. The evaluation of the process must be completed prior to claiming new technology.